

1 We claim:

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3 1. An apparatus for optically coupling light between an optical fiber and  
4 a substrate, comprising:

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6 a waveguide grating coupler disposed on the substrate

7 and

8 an optical fiber comprising: a core and a cladding, with an angled tip,

9 where the angled tip of the fiber:

10 is positioned on the surface of a substrate with the core of the fiber  
11 substantially parallel to the surface of the substrate, and the cladding  
12 on the longer side of the angled tip is adjacent to the surface of the  
13 substrate,

14 and

15 has a reflective surface with an angle of less than 45 degrees to the  
16 surface of the substrate, and the reflective surface is positioned  
17 adjacent to the waveguide grating coupler disposed on the substrate.

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19 2. An apparatus according to claim 1, wherein the reflection of light at  
20 the reflective surface is substantially total internal reflection.

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22 3. An apparatus according to claim 1, and further comprising a coating  
23 on the exterior of the reflective surface, where the material comprising the  
24 coating is selected from one of the following: a dielectric, a plurality of  
25 dielectric layers, epoxy, a metal and a first layer comprised of metal and a  
26 second layer comprised of epoxy.

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2 4. An apparatus according to claim 3, wherein the metal is selected from  
3 one of the following: aluminum and gold.

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5 5. An apparatus according to claim 1, wherein the shape of the  
6 reflective surface is substantially flat.

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8 6. An apparatus according to claim 1, wherein light reflecting off the  
9 reflective surface and propagating to the substrate is a diverging beam of  
10 light.

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12 7. An apparatus according to claim 1, wherein light propagating from  
13 the waveguide grating coupler to the reflective surface is a converging beam  
14 of light.

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16 8. An apparatus according to claim 1, wherein the waveguide grating  
17 coupler couples light between the fiber and a planar waveguide disposed on  
18 the substrate.

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20 9. An apparatus according to claim 1, and further comprising a flat  
21 section on the cladding adjacent to the angled tip of the fiber, where the flat  
22 section:

23 is oriented parallel to the core of the fiber,

24 is positioned on the longer side of the angled tip,

25 is aligned adjacent to and on top of the waveguide grating coupler,

26 and

1 is positioned in substantial contact with the surface of the substrate.

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3 10. An apparatus according to claim 9, wherein the flat section forms a  
4 stigmatic lens in the optical path between the reflective surface of the  
5 angled tip of the fiber and the surface of the substrate.

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7 11. An apparatus according to claim 1, and further comprising  
8 mechanical bonding of the fiber to the substrate with epoxy.

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10 12. An apparatus according to claim 1, and further comprising  
11 mechanical bonding of the fiber to a pedestal with epoxy.

12

13 13. An apparatus according to claim 12, and further comprising  
14 mechanical bonding of the pedestal to the substrate with epoxy.

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16 14. An apparatus according to claim 1, and further comprising bonding of  
17 the fiber to a connector with one of the following: a mechanical bond and  
18 epoxy.

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20 15. An apparatus according to claim 14, and further comprising bonding  
21 of the connector by one of the following:

22 using epoxy to bond the connector to the substrate,

23 using epoxy to bond the connector to a package enclosing the substrate,

24 using solder to bond the connector to the substrate,

25 using solder to bond the connector to a package enclosing the substrate,

26 using a mechanical bond to bond the connector to the substrate

1 and  
2 using a mechanical bond to bond the connector to a package enclosing the  
3 substrate.

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5 16. An apparatus according to claim 1, and further comprising a metallic  
6 coating applied to a section of the cladding of the fiber, where the  
7 metallized section of the cladding is not in the optical path of light  
8 propagating between the reflective surface and the substrate.

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10 17. An apparatus according to claim 16, and further comprising  
11 mechanical bonding of the metallized section of the cladding of the fiber to  
12 the substrate with solder.

13

14 18. An apparatus according to claim 16, and further comprising  
15 mechanical bonding of the metallized section of the cladding of the fiber to  
16 a pedestal with solder.

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18 19. An apparatus according to claim 18, and further comprising  
19 mechanical bonding of the pedestal to the substrate with a material selected  
20 from one of the following: epoxy and solder.

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22 20. An apparatus according to claim 1, and further comprising an  
23 automated system for the alignment of the angled tip of the fiber to the  
24 waveguide grating coupler on the substrate.

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1 21. An apparatus according to claim 20, and further comprising an  
2 automated system for the alignment of the angled tip of the fiber in the  
3 longitudinal direction of the fiber to the waveguide grating coupler on the  
4 substrate.

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6 22. An apparatus according to claim 20, and further comprising an  
7 automated system for the alignment of the angled tip of the fiber in the  
8 lateral direction of the fiber to the waveguide grating coupler on the  
9 substrate.

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11 23. An apparatus according to claim 20, and further comprising an  
12 automated system for the alignment of the angled tip of the fiber with  
13 respect to the height of the fiber above the waveguide grating coupler on the  
14 substrate.

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16 24. An apparatus according to claim 1, wherein the optical fiber is  
17 selected from one of the following: a single mode fiber and a polarization  
18 maintaining fiber.

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20 25. An apparatus according to claim 1, wherein the optical fiber is a  
21 polarization maintaining fiber (PMF) with a mode polarized parallel to the  
22 surface of the substrate.

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24 26. An apparatus according to claim 1, wherein the substrate is selected  
25 from the group comprising: silicon, silicon on insulator (SOI), silicon on  
26 sapphire (SOS), silicon on nothing (SON) and

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a first layer of monocrystalline silicon,  
a second layer of dielectric material disposed on the first layer,  
a third layer of monocrystalline silicon disposed on the second layer,  
a fourth layer of dielectric material disposed on the third layer,  
a fifth layer of monocrystalline silicon disposed on the fourth layer.

27. A method of fabricating an apparatus for coupling light between an  
optical fiber and a waveguide grating coupler disposed on a substrate,  
comprising:  
forming an angled tip with a reflective surface on the fiber by cutting the  
fiber at an angle of less than 45 degrees with respect to the core of the fiber,  
positioning the longer side of the angled tip of the fiber on top and adjacent  
to the waveguide grating coupler,  
and  
bonding the angled tip of the fiber to the substrate.

28. The method of claim 27, wherein forming the angled tip further  
comprises:  
flattening the reflective surface by polishing the reflective surface, after the  
fiber has been cut.

1 29. The method of claim 27, wherein forming the angled tip further  
2 comprises:  
3  
4 coating the reflective surface with a coating, after the fiber has been cut,  
5 where the coating is selected from one of the following: a dielectric, a  
6 plurality of dielectric layers, epoxy, a metal and a first layer comprised of  
7 metal and a second layer comprised of epoxy.

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9 30. The method of claim 27, wherein positioning further comprises:  
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11 propagating a light through the optical fiber towards the reflective surface,  
12 and  
13 aligning the angled tip of the fiber with respect to the waveguide grating  
14 coupler by maximizing the amount of light coupled from the reflective  
15 surface through the waveguide grating coupler.

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17 31. The method of claim 27, wherein positioning further comprises:  
18  
19 propagating a light through the waveguide grating coupler towards the  
20 reflective surface,  
21 and  
22 aligning the angled tip of the fiber with respect to the waveguide grating  
23 coupler by maximizing the amount of light coupled to the optical fiber  
24 through the reflective surface.

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26 32. The method of claim 27, wherein bonding further comprises:

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2 using epoxy to bond the angled tip of the fiber to the substrate.

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4 33. The method of claim 27, wherein bonding further comprises:

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6 using epoxy to bond the angled tip of the fiber to a pedestal

7 and

8 using epoxy to bond the pedestal to the substrate.

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10 34. The method of claim 27, wherein bonding further comprises:

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12 bonding the angled tip of the fiber to a connector using one of the

13 following: epoxy, solder and a mechanical bond

14 and

15 bonding the connector to the substrate using one of the following: epoxy,

16 solder and a mechanical bond.

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18 35. The method of claim 27, wherein bonding further comprises:

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20 bonding the angled tip of the fiber to a connector using one of the

21 following: epoxy, solder and a mechanical bond

22 and

23 bonding the connector to a package enclosing the substrate using one of the

24 following: epoxy, solder and a mechanical bond.

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26 36. The method of claim 27, wherein bonding further comprises:



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2 applying a metal coating to a section of the cladding of the fiber, where the  
3 metallized section of the cladding is not in the optical path of light  
4 propagating between the reflective surface and the waveguide grating  
5 coupler disposed on the substrate,  
6 and

7 bonding the metallized section of fiber to the substrate with solder.

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9 37. The method of claim 27, wherein bonding further comprises:

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11 applying a metal coating to a section of the cladding of the fiber, where the  
12 metallized section of the cladding is not in the optical path of light  
13 propagating between the reflective surface and the waveguide grating  
14 coupler disposed on the substrate,  
15 bonding the metallized section of fiber to a pedestal with solder,  
16 and

17 bonding the pedestal to the substrate with a material selected from one of  
18 the following: epoxy and solder.

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20 38. The method of claim 27, wherein bonding further comprises:

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22 forming a flat section on the cladding adjacent to the angled tip of the fiber,  
23 where the flat section is on the longer side of the angled tip, and the flat  
24 section is oriented parallel to the core of the fiber,

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1 aligning the flat section adjacent to and on top of the waveguide grating  
2 coupler,

3

4 positioning the flat section in substantial contact with the surface of the  
5 substrate,

6 and

7 bonding the planar section to the substrate with epoxy.

8

9 39. The method of claim 27, wherein the optical fiber is a polarization  
10 maintaining fiber (PMF) and forming the angled tip further comprises:

11

12 selecting the mode of the PMF to be propagated through the apparatus,

13 where the selected mode is polarized parallel to the surface of the substrate,

14 and

15 forming the angled tip with a reflective surface on the fiber by cutting the

16 fiber at an angle of less than 45 degrees with respect to the plane of the

17 selected mode.

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